PROCESS DAMPING TECHNIQUE FOR ALUMINIUM ALLOY AT LOW SPEED MACHINING

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ABSTRACT

This thesis investigated the process damping performance of tools when machining aluminium alloy at low speed. The objective of this thesis is to prepare the aluminum alloy workpiece for cutting experiment. Second objective of this project is machining the aluminium alloy workpiece with process damping technique which is using high axial depth of cut and low radial depth of cut. The third objective is to compare process damping performance between three different helix tools. The thesis implants process damping techniques to investigate the fatigue process damping performance between tool types. All tools used in this project are uniform helix tools which represent by solid carbide tool, high speed steel coated tool and solid carbide coated tool. By performing machining which is milling process on CNC Haas VF6 vertical milling machine, data for process damping performance is recorded. From the data, process damping wavelength will be calculated for the comparison of performance. The result obtained indicated that the solid carbide tool have the lowest process damping wavelength while high speed steel coated tool have higher process damping wavelength than solid carbide coated tool. The highest process damping wavelength goes to solid carbide coated tool. As a conclusion, solid carbide coated gave the best performance of machining aluminium alloy at low speed.

ABSTRAK

Tesis ini berkaitan dengan prestasi proses redaman untuk alat apabila pemesinan aloi aluminium pada kelajuan rendah di lakukan. Objektif tesis ini adalah menyediakan bahan kerja aluminium aloi untuk eksperimen memotong. Objektif kedua ialah memesin bahan kerja aluminium aloi dengan teknis proses redaman yang menggunakan nilai tinggi bagi kedalaman paksi kedalaman dipotong dan nilai rendah dalam jejari kedalaman pemotongan. Objektif ketiga ialah untuk membandingkan prestasi proses redaman antara tiga alat helix yang berbeza.Implan tesis memproses teknik redaman adalah untuk menyiasat prestasi proses redaman lesu antara jenis alat. Semua alat yang digunakan dalam projek ini adalah jenis helix seragam yang diwakili oleh alat karbida pepejal,alat keluli bersalut berkelajuan tinggi dan alat karbida pepejal bersalut. Dengan melakukan pemesinan yang merupakan proses penggilingan menggunakan mesin Komputer Kawalan Berangka Haas VF6, data untuk prestasi proses redaman direkodkan. Daripada data yang didapati, panjang gelombang proses redaman akan dikira untuk membandingkan prestasi proses redaman. Keputusan yang diperolehi menunjukkan bahawa alat karbida pepejal mempunyai panjang gelombang proses redaman yang terendah manakala alat keluli berkelajuan tinggi mempunyai panjang gelombang proses redaman yang lebih tinggi. Panjang gelombang proses redaman yang tertinggi didapati oleh alat karbida pepejal bersalut. Keputusan menyimpulkan bahawa alat karbida pepejal bersalut memberikan prestasi terbaik dalam pemesinan aluminium aloi pada kelajuan rendah.

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LIST OF SYMBOLS

λ_c	Process damping wavelength
h_{max}	Maximum chip thickness
fpt	Feed per tooth
μ	Micro
γ	Relief angle

LIST OF ABBREVIATIONS

AA	Aluminum alloy
Al	Aluminium
BHN	Briness Hardness Number
C	Carbon
CBN	Cubic boron nitride
Co	Cobalt
CNC	Computer numerical control
Cr	Chromium
Cu	Copper
CVD	Chemical vapour deposition
Fe	Iron
FRF	Frequency response function
HSS	High speed steel
Li	Lithium
Mn	Manganese
Mo	Molybdenum
MRR	Material removal rate
Ni	Nickel
Sn	Stannum
Ti	Titanium
TaC	Tantalum carbide
TiC	Titanium carbide
UTS	Ultimate tensile strength

V	Vanadium
W	Tungsten
WC	Tungsten carbide
Zn	Zinc
Zr	Zirconium

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Aluminium alloy is a silverish white metal that is very light compared to other metals such as brass, nickel, steel and copper. It has a very strong corrosion resistance and also a good electrical conductivity. Furthermore, aluminium alloy is having good machinability as it can be turned, milled and bored in the machining process. Aluminium alloy have been the prime material of construction for the aircraft industry for making aircraft airframes. Besides that, it’s also widely used in sports equipment and also for high pressure gas cylinders. The costs of aluminium alloy are relatively low compared to titanium alloy. So, in this project, technique to machine this aluminium alloy is done to investigate the process damping performance between different tool types.

A good machinability is one of the characteristics or the advantage of aluminium alloy. In milling process chatter can still be occur and gives bad surface finish to the machined surface. Chatter is one problem that needs to be overcome as it can damage the tools and the machines itself. Process damping performance for tools when milling this material will be observed. At low cutting speed process the damping process will occur. The process damping region can be known by observing chatter stability diagram

Therefore, in this project, frequency response of function is initially determined for the flexural system of single degree of freedom. Low radial and high depths of cut are used as cutting process for achieving damping behaviour at low speed. Chatter frequency and surface speed is use to determine process damping performance. A regular milling tool performance which is regular solid carbide is compared with solid carbide coated tool and High Speed Steel (HSS) coated tool.

1.2 PROJECT OBJECTIVES

These are the objective of this research:

i. To prepare Aluminium Alloy workpiece.
ii. To machining Aluminium Alloy using uniform helix milling tools with process damping technique.
iii. To compare process damping performance between three different helix milling tools.

1.3 PROJECT SCOPES

The project needs to prepare workpiece of the material which is Aluminium Alloy. The flexural holds the workpiece also need to be done. Then, the frequency response of the flexural should be determined. When machining Aluminium Alloy using CNC milling machine, it needs to use low radial and high axial depth of cut. Cutting tools for the machining process should be varying in type which are regular solid carbide tool and coated tools. Process damping performance between the tools was then compared. The flow of the project is as in Figure 1.1.The activities done throughout this research are shown in Appendix A.

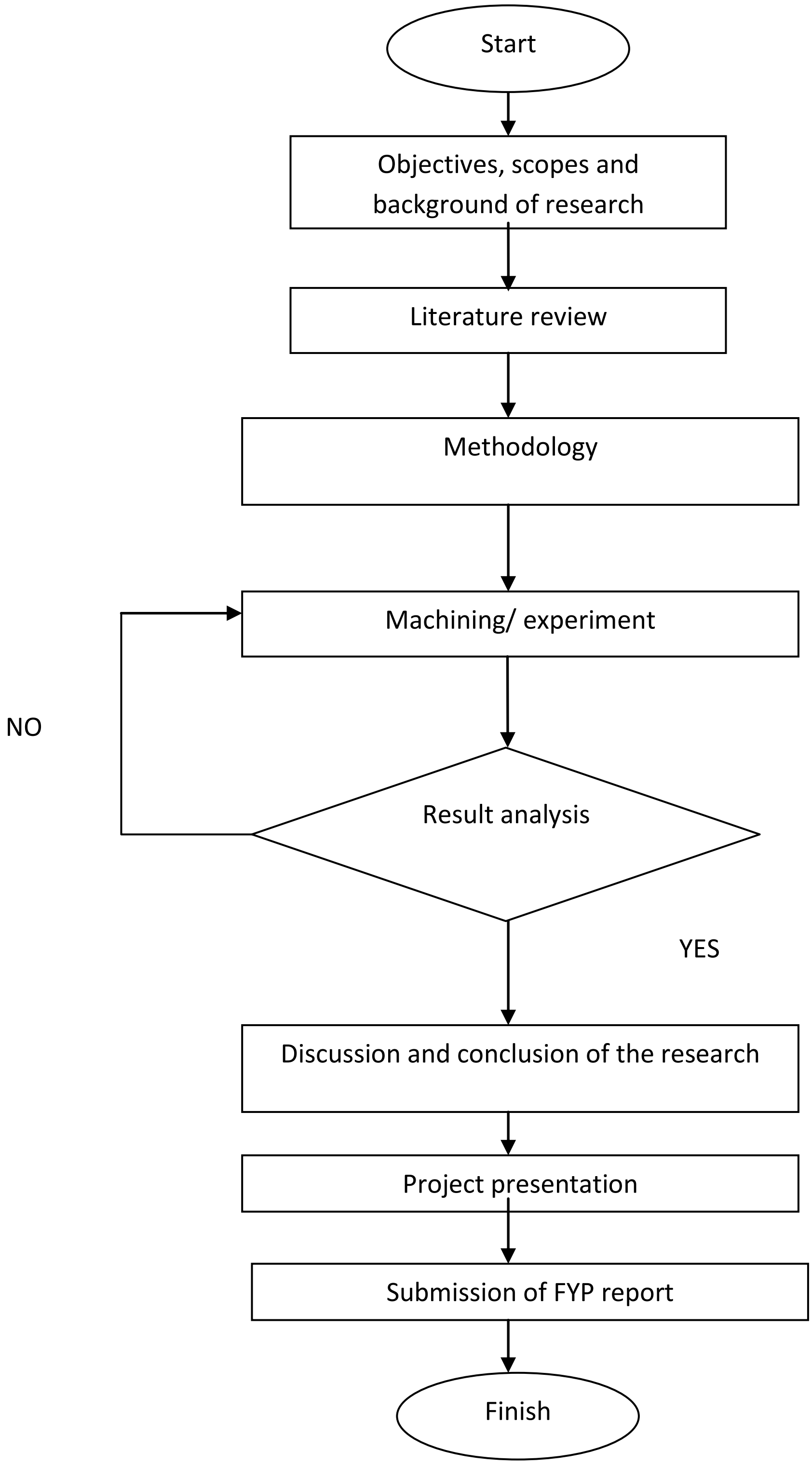

Figure 1.1: Flow chart of the project

CHAPTER 2

LITERATURE REVIEW

2.1 ALUMINIUM ALLOYS

Aluminium alloy are categorized in two types which is cast alloys and wrought alloys. Cast alloys is the alloy that solidified from liquid and used without any mechanical processing while wrought alloy is involving mechanical processing. Their identification and designations are referred to Aluminium Association. This association divide these alloys into different nomenclatures. Two-and three-digit numbers are used for castings whereas four-digit designations are used for wrought alloys.

Aluminium with additives among Cu, Mn, Si, Mg, Mg+Si, Zn and Cu+Li are normally applied. Based on these, the 2xxx (Al-Cu) ,the 6xxx (Al-Mg-Si) and the 7xxx (Al-Zn) alloys are strengthened by aging or precipitation hardening process, to strength levels corresponding to those of low strength alloy steels up to 100ksi UTS and 90-95 ksi yield strength. The highest strengths results in the Al-Zn alloy such as AA 7075 in the age hardened tempers T4 or T6. Therefore, the 7xxx series alloy has been designated as high strength Al-alloys. The compositions and temper designations for aluminium alloy are shown in Table 2.1. The temper designation for aluminium alloys are stated as follows:

i. F-As fabricated, O-Annealed, H-Strain hardened, W-Solution heat-treated.
ii. T- Thremally-treated to produce stable tempers other than F, O and H.
iii. T2-Annealed (for cast product only)

iv. T4-Solution heat-treated and naturally aged at room temperature to substantially stable condition with maximum hardness and strength.
v. T6-Solution heat-treated and then artificially aged at elevated temperature.
vi. T7-Solution heat-treated and then stabilized by overaging treatment.

These high strength Al-alloys in T4 or T6 condition have low ductility and fracture toughness and also prone to stress corrosion cracking. Although the fracture cannot be increased to high levels, equivalent to those found in some quenched and tempered steels, the alloys can be made to resist stress corrosion cracking by treating then to an overage temper T7.As an alternative, high-purity Al-alloys with negligible silicon and iron such as AA 7049 and 7050 can be used. They are immune to stress corrosion cracking in their T6 temper. As the Al-alloys have good thermal conductivity, it helps vastly in engine piston application for example in the selection of using AA 7075-T6 for this application. For high strength Al-alloys, especially the Al-Cu duralumin alloys are commonly used in airframe and airfoil applications. Al-alloys also used in gas turbine engine air compressors and also in transport for wheels and propellers.

Table 2.1: Composition of selected Aluminium Alloys

Alloy No.	Wt.% Alloy Elements	Major Applications
1100	0.12 Cu	
2017	4.0 Cu, 0.5 Mn, 0.5 Mg	
2024	4.5 Cu, 0.6 Mn, 1.5 Mg	
3003	1.2 Mn, 0.12 Cu	
4032	12.2 Si, 0.9 Cu, 1.1 Mg, 0.9 Ni	
4043	5.0 Si	
5056	5.2 Mg, 0.1 Mn, 0.1 Cr	
6061	1.0 Mg, 0.6 Si, 0.25 Cu, 0.2 Cr	
6063	0.7 Mg, 0.4 Si	
7075	5.6 Zn, 1.6 Cu, 2.5 Mg, 0.3 Cr	
7178	6.8 Zn, 2.0 Cu, 2.7 Mg, 0.3 Cr	
7049	7.6 Zn, 1.5 Cu, 2.5 Mg, 0.15 Cr, 0.25 Si, 0.35 Fe	
7050	6.3 Zn, 2.4 Cu, 2.3 Mg, 0.04 Cr, 0.12 Si, 0.15 Fe	
7175	5.6 Zn, 1.6 Cu, 2.5 Mg, 0.24 Cr,	
43	4.5-6.0 Si, 0.8 Fe,0.1Cu, 0.3 Mn, 0.2 Zn, 0.2 Ti	
A132	11.0-13.0 Si, 1.3 Fe, 0.5-1.5 Cu, 0.7-1.3 Mn, 2.0-3.0 Ni, 0.2 Ti	Low expansion piston in IC engines
355	4.5-5.5 Si, 0.6 Fe, 1.0-1.5 Cu, 0.3 Mn, 0.4-0.6 Mg, 0.2 Zn	

Source: Raman (2007)

2.2 CHATTER

Chatter is produced from self-excited vibration during cutting resulting in high amplitude unstable motion. Self-excited vibrations are based on regeneration of the waviness of the surface generated in subsequent cuts. These subsequent cuts are produced by adjacent teeth of the cutter as seen in Figure 2.1. Every cutter removes the material from an undulated surface left by the previous cutter, and leaves behind another undulated surface which becomes the source of self-excitation. It has been shown that at a given speed, increasing the cutter diameter causes the drillstring to transform from a stable system, where vibrations tend to die out, to a system where vibrations build up over time (chatter) until they reach saturation. Saturation can be caused by process nonlinearities such as the cutter jumping out of the cut.

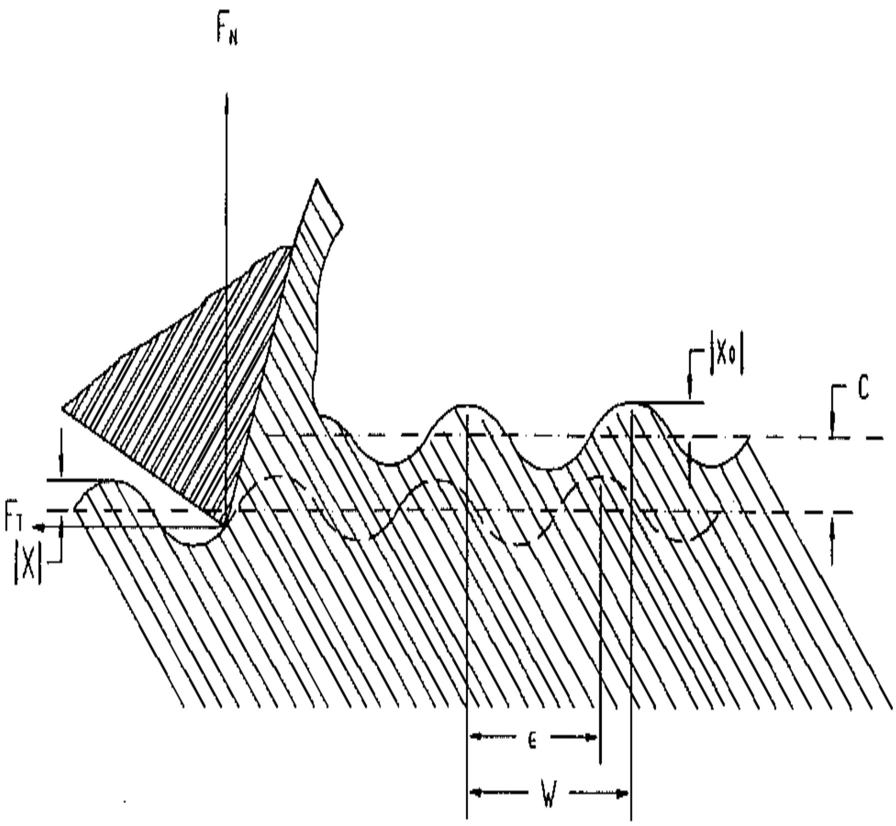

Figure 2.1: Surface generate on typical cutter

Source: Eslayed *et al*. (1994)

Referring to Figure 2.1, the cutting force can be written as (Zamudio, 1988),

$$F = bK_s(C + X_o - X) \tag{2.1}$$

where;

b = width of cut (m)
K_s = cutting stiffness of rock formation (N/m^2)
C = average feed per cutter blade (m)
X = magnitude of current surface undulation (m)
X_o = magnitude of previous surface undulation (m)

Since C is constant, the variable part of the force causing the vibration is;

$$F = bK_s(X_o - X) \tag{2.2}$$

This is a simplified form of the force, where K_s is a real number and the effect of process damping is not included. (X_o-X) is the change in surface position between current and previous cuts. The effect of process damping on the force was considered by many investigators to be included in the imaginary component of one of the parameters affecting the cutting force. These parameters are referred to as dynamic cutting force coefficients (DCFCs) by Tlusty (1978) and Das and Tobias (1967).

Basically in theory, the stability boundary is then independent of the feed rate despite the influence of the feed rate on the mean chip thickness. Apparently, in real process the empirical cutting stiffness K_s, changes with the feed rate so that the feed rate does have some influenced on the overall stability.

The feed rate is better express in term of the maximum chip thickness, h_{max} ;

$$h_{max} = fpt\sqrt{\frac{4r}{D} + \left(\frac{2r}{D}\right)^2} \tag{2.3}$$

From the equation above, r is the radial immersion of the tool, and D is the tool diameter, *fpt* represents feed per tooth which is related to the machining feed rate *f*, number of teeth m, and spindle speed n .This is shown in the equation 2.4:

$$f = m \times fpt \times n \tag{2.4}$$

When a high depth of cut are used at low cutting speed, it will results that the chatter stability will be dominated by process damping effects .Low radial immersion function to reduce the total machining forces and improve the tool life. This approach will be employed in the present study in order to determine the process damping wavelength, λ_c under different tools types.

2.3 REGENERATIVE CHATTER THEORY

Regenerative chatter is a self-excited vibration that can occur during milling and other machining processes. It leads to a poor surface finish, premature tool wear, and potential damage to the machine or tool. Variable pitch and variable helix milling tools have been previously proposed to avoid the onset of regenerative chatter.

As an example, consider a milling tool (such as that shown in Figure 2.2), that shows process in up-milling a workpiece. The forces and displacements on a plane normal to tool axis are shown schematically in Figure 2.3. The forces acting on each tooth can be considered to be a function of the thickness of the chip being removed by that tooth. These forces will cause a relative motion between the tool and the workpiece in the x and y directions. This relative motion imparts a wavy surface finish on the just cut workpiece, and as the tool rotates this wavy surface is cut by the next tooth. The chip thickness is therefore a function of the current relative displacement and that when the previous tool was cutting the workpiece at this location. The result is a natural feedback process, or self-excited vibration, that can be represented by the schematic block diagram in Figure 2.4.

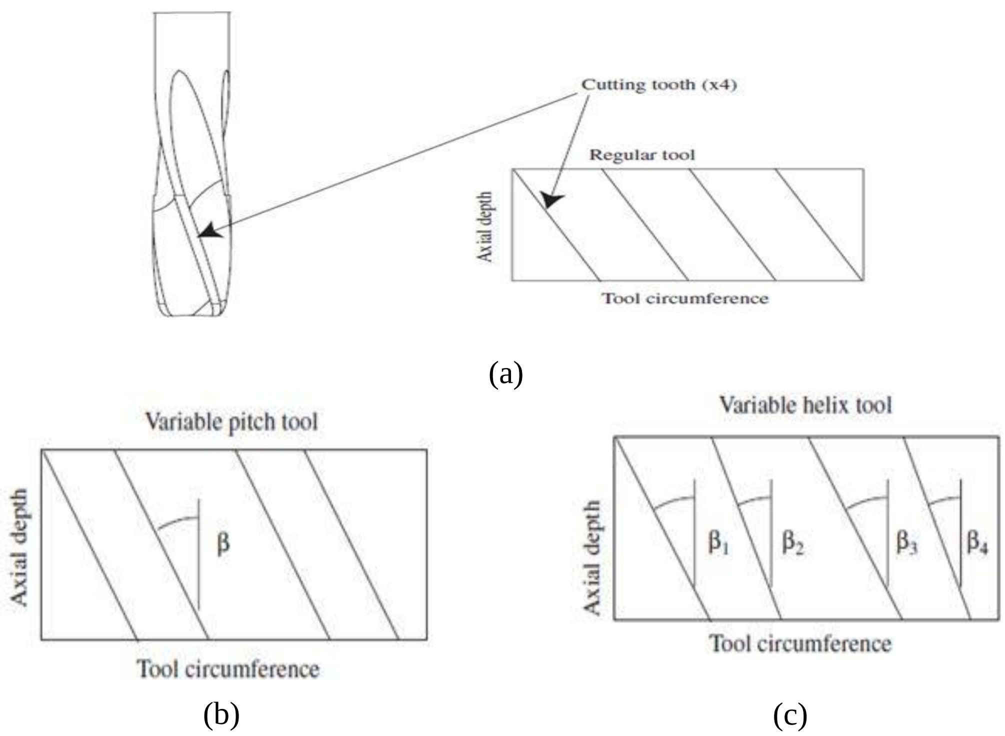

Figure 2.2: Milling tool geometry; (a) Uniform tool, (b) variable pitch tool and (c) variable helix tool

Source: Sims *et al.* (2008)

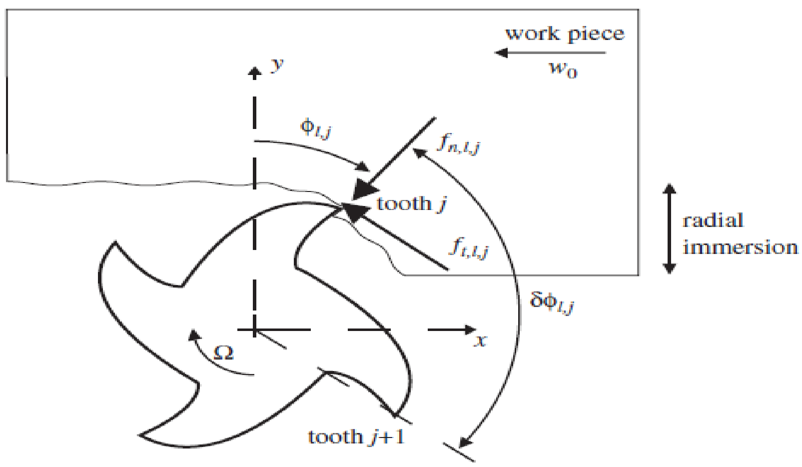

Figure 2.3: Forces on axial slice *l* of a tool (up milling)

Source: Sims *et al*. (2008)

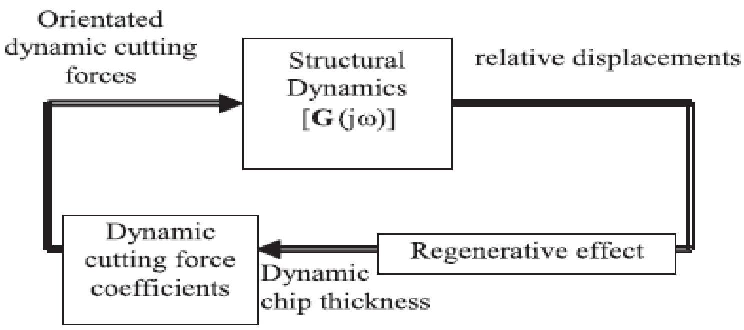

Figure 2.4: Schematic block diagram for regenerative chatter in milling

Source: Sims *et al*. (2008)

2.4 PROCESS DAMPING

One of the most important chatter mechanisms is the process damping force which has a great influence on cutting process stabilization at low cutting speeds. It has been shown in experiment that process damping is generated at the interface between the tool flank and machined surface during dynamic cutting. This process damping is a very significance source of increased stability in machining particularly at low cutting speeds. Tlusty and Ismail (1983) showed that the process damping has significant effect on chatter stability decreasing with cutting speed. Besides, the damping produce from the structure from the machine tools, machining process itself can add damping to the system through a phenomenon known as process damping. The term process damping force or resistance was introduced by Tobias and Fishwicks (1958). They proposed that such force when tool flank or relief face rubs against the wavy workpiece surface at low spindle speed.

Identification and modelling of process damping is addressed as one of the unsolved problems in metal cutting by Altintas and Weck (2004). There have been many attempts to study process damping in turning operation using simulation or experiment method compared to studies in milling operation. One of the main objectives of machining research is to increase productivity which can be achieved by proper selection of cutting conditions. Cutting depth directly affects the material removal rate, and thus productivity, but it is usually limited due to chatter vibrations.

In high speed machining, stability lobes where higher stable depth of cuts are available can be utilized, whereas in low speed cutting the process damping may have significant effect on stability. It is well known that higher stable cutting depths can be achieved under the effect of process damping.

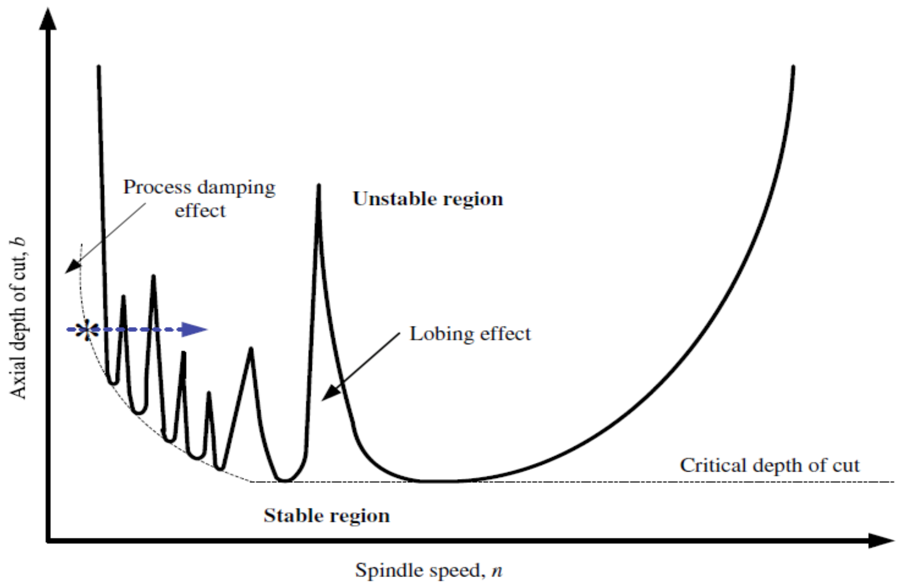

Figure 2.5: Chatter stability lobe

Source: Yusoff *et al*. (2010)

The stability diagram in Figure 2.5 shows the relationship between spindle speeds, depth of cut and chatters stability. The horizontal arrow represents a constant depth of cut with an increasing spindle speed, and the asterisk marker shows the spindle speed at which process damping no longer prevents severe chatter. At high spindle speeds, stability lobes can be observed and this allow high productivity cutting to be performed on easy to machine materials such as Aluminium Alloys. The resulting high surface speed are not compatible with more difficult to machine material such as Titanium Alloys. In this case using low spindle speed is more preferable, where chatter stability is strongly influenced by process damping phenomenon. At low speeds, the wavelength λ of these surface waves is much smaller since the wavelength is proportional to surface velocity v and inversely proportional to regenerative vibration frequency, f_c as in equation 2.5;

$$\lambda = \frac{v}{f_c} \tag{2.5}$$

Forces generated on the cutter are caused not only by the changing thickness of material, but also by interference between the cutter and the previously generated surface. This is the source of process damping. Figure 2.6 shows how process damping develops (Delio, 1989). Damping is produced by the action of the normal force on the tooth. This normal force is dependent on the slope of the surface relative to the relief surface of the cutter edge. The amount of interference between the cutter and the surface depends on the tool relief angle and surface wavelength. The interference produces a varying oscillatory normal force. This force is 90 degree out of phase with the motion of the tool and represents a damping force. As can be seen from Figure 2.6, the minimum relief angle between the tool and the surface occurs at point B producing the maximum upward normal force. This point also corresponds to the point of maximum downward velocity of the tool. As can be seen, this force is opposing the motion. Conversely, at point D, the clearance angle is at maximum and the variational normal force is at minimum. Here the tool is at a maximum velocity in an upward (and minimum in a downward) direction with the minimum variational normal force. It can be seen that tool surface interference inhibits the motion in phase with the tool velocity, and thus the generated force is referred to as a process damping force.

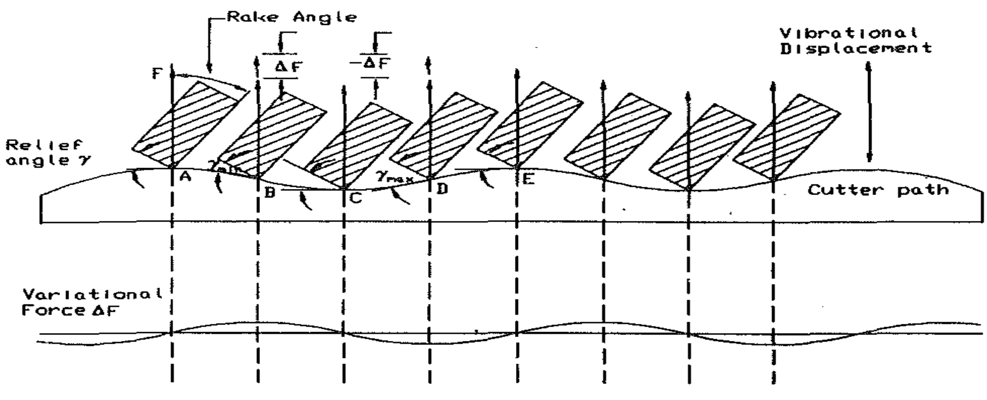

Figure 2.6: Mechanism of process damping

Source: Eslayed *et al*. (1994)

2.5 CUTTING TOOL MATERIAL

Ability to increase metal removal rates depends primarily on the development of cutting tool material. The material removal rate, MRR=*bhv*, can be increased by increasing either width of chip *b*, or the chip thickness, or the cutting speed *v*. The increase of chip thickness leads to tool breakage or faster tool to wear and increase the cutting speed will increase the tool wear rate. Tool wear rate also known as tool life is depends on *h* and *v* in the economy of machining. In Figure 2.7 the improvement of cutting time for different cutting material used was illustrated.

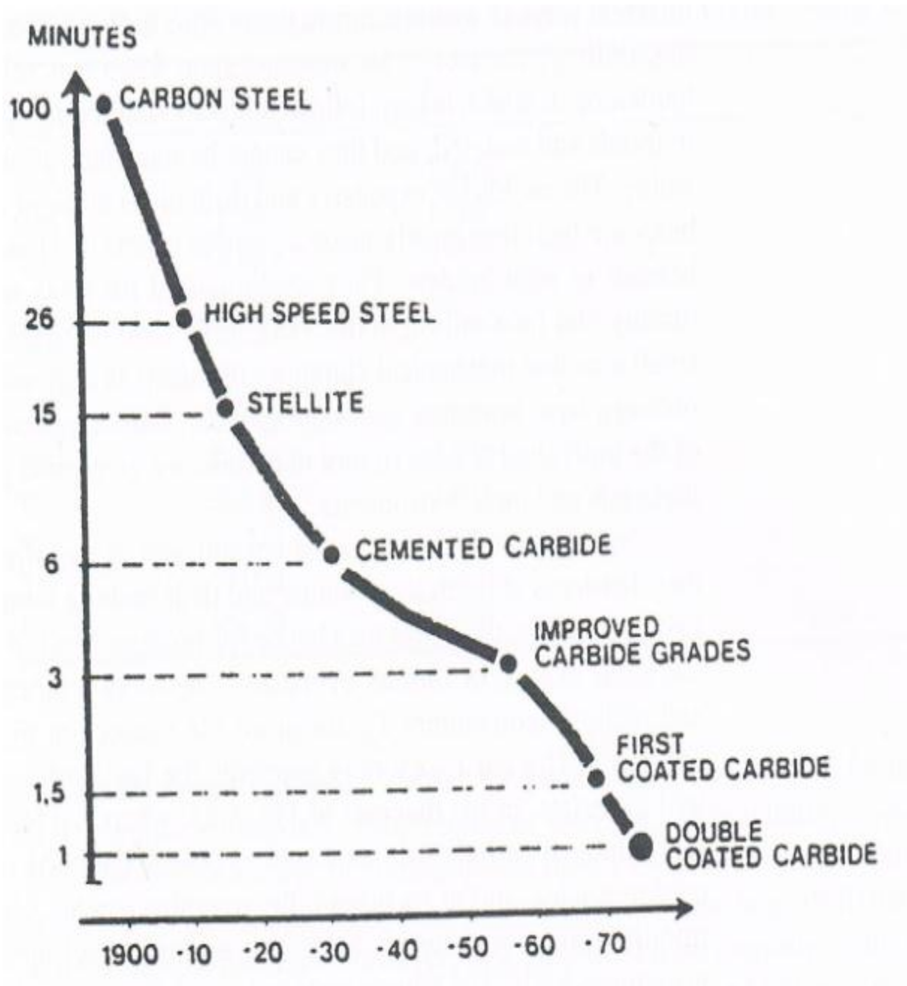

Figure 2.7: Change in cutting time over the past ninety years for machining a 100mm diameter, 500mm long steel shaft with different cutting material.

Source: Tlusty (2000)